OBSERVING RESULTS OF NUCLEAR EXPERIMENTS

. . . Measurement and detection of radiation

To perform nuclear experiments, instruments must be used that are capable of recording and measuring the motion of nuclear particles, particles so small that they would have to be magnified 10 billion times to be seen by the naked eye.

Most of these detection devices depend upon *ionization,* which is simply the acquisition by a neutral atom of an electric charge. This charge can be acquired when a high energy particle, striking the neutral atom, dislodges one of the atom's electrons. The newly charged atom is called an *ion.* Instruments built to take advantage of this principle include Geiger and proportional counters, ionization chambers, and cloud chambers.

GEIGER AND PROPORTIONAL COUNTERS

Counter: in its simplest form, one of these counters consists of a fine wire supported along the axis of a metal cylinder, with a strong positive charge on the wire.

Operation: A particle or gamma ray entering the tube dislodges electrons from atoms encountered. The negative electrons, attracted to the positively charged wire, brush off other electrons in their rush to the wire. There is a veritable avalanche of electrons propelled to the wire.

Counting: The avalanche, or discharge, produces an electric pulse, which may be amplified and registered on a mechanical counter. A Geiger counter registers all entering particles. A proportional counter is more useful, for it distinguishes particles of different types and energies by the size of the electrical pulses.

IONIZATION CHAMBERS

Ionization Chambers, consisting of two oppositely charged plates in a gas filled chamber, are similar in principle to Geiger counters.

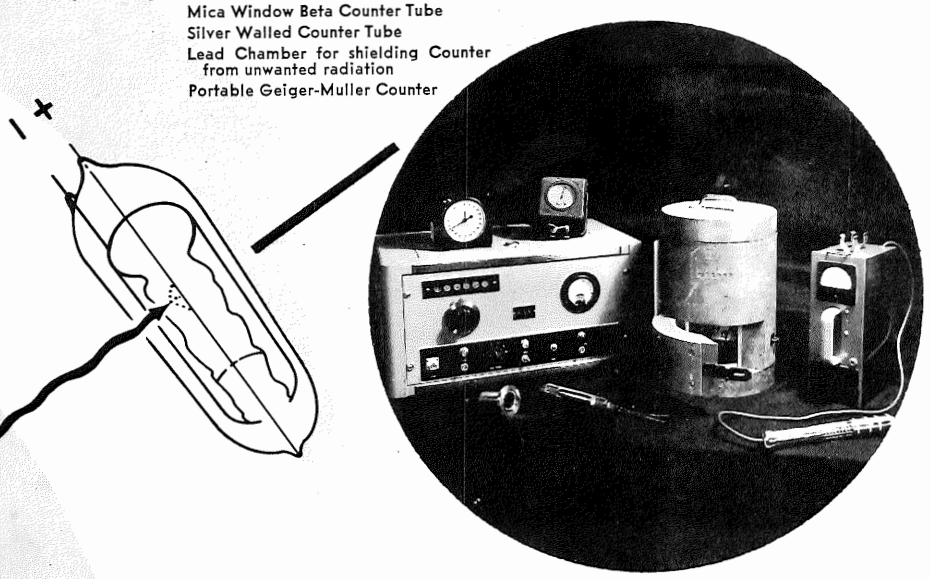
Operation: Radiations passing through a gas in the chamber knock electrons off some of the atoms of gas. The electrons are collected by the positively charged plate, the positive ions by the negatively charged plate.

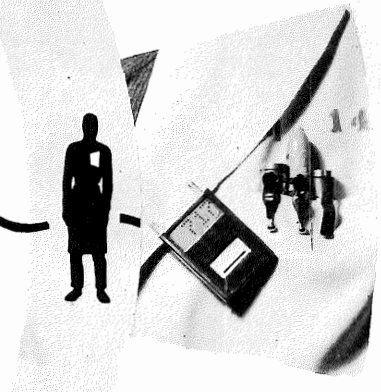
Measurement: The collected particles give rise to small electrical pulses, which may be detected directly by a sensitive electrometer or amplified to give reading on ordinary meters.

USES OF RADIATION DETECTORS

Geiger and proportional counters and ionization chambers are adaptable to many purposes in atomic research. They are used to determine the kind, strength and quantity of radiations from a given source. With such information, researchers can protect themselves and their associates from overexposure to radiation; trace radioactive atoms through animals and plants and chemical processes; ferret out new facts about the inner workings of the atom by deducing the conditions giving rise to radiations; and discover new elements and isotopes.

(Left to right) Scaler, Timer and Register
Mica Window Beta Counter Tube
Silver Walled Counter Tube
Lead Chamber for shielding Counter from unwanted radiation
Portable Geiger-Muller Counter





Photographic Film Badge and Pocket Ionization Chambers worn by workers to detect exposure to radiation

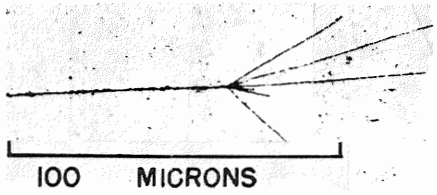
(Left to right) Portable Ionization Chamber for radiation survey
Special Ionization Chamber for medical application
Ionization Chamber for alpha radioactivity

THE PHOTOGRAPHIC-PLATE METHOD OF STUDYING HIGH-SPEED PARTICLES

A solid block of sensitive emulsion is made up of many sheets or pellicles. Each is thin enough to be chemically processed and studied under the microscope.

When a charged particle passes through this block it leaves a trail of developable grains behind it. When developed this becomes the "track" of the particle and is visible in a high-power microscope. Protons and neutrons may react with atoms of the emulsion, giving rise to charged particles, and thus register indirectly.

A one-mil rectangular grid is contact-printed on each pellicle. After development, while still wet, each pellicle is mounted on special glass slides. Guided by the grid one is able to follow a track through a whole block of emulsions.

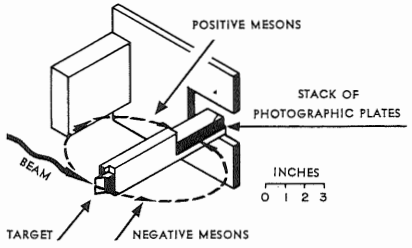


From these emulsions, physicists can tell a great deal about the particles making the tracks. The mass of the particle and its energy can be calculated from the appearance of the track and its length. Of particular interest are "stars," the explosions of emulsion nuclei into many fragments when struck by high-energy atomic projectiles. Studies of such events add to existing knowledge of nuclear reactions and of the nuclear particles involved.

EARLY METHOD OF PRODUCING MESONS

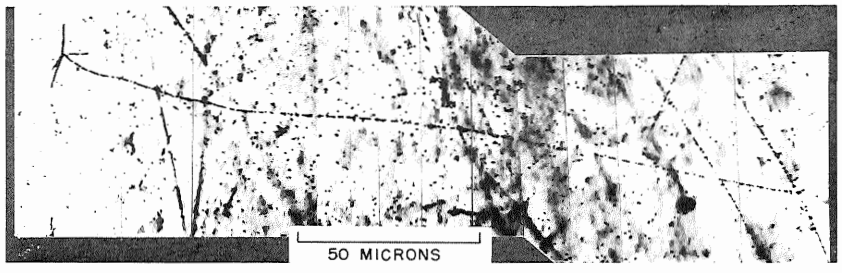
Mesons are at present key particles of nuclear physics, for they appear to be intimately tied up with the forces that hold the nucleus together.

Detected by counters and cloud chambers as well as by photographic film, mesons have been studied for several years at sea level, on mountain tops, and in airplanes and balloons.



Man-made mesons were first detected on February 21, 1948 in bombardments with the 184-inch synchrocyclotron. When the higher energies of the Bevatron became available the number and kind of mesons were greatly increased. Their mass varies between approximately 200 and 1,000 electron units. They are short-lived (less than one-millionth of a second) and after varied decay schemes end up mostly as energy (heat). Many laboratories are trying to bring order to the present chaotic situation.

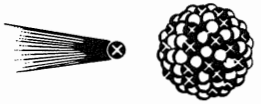
FIRST PUBLISHED PHOTOGRAPH OF MAN-MADE MESONS



HIGH-ENERGY PARTICLES FROM ACCELERATORS ARE USED . . .

TO BREAK ATOMS APART
TO PRODUCE ARTIFICIAL RADIOACTIVITY
TO DISCOVER NEW ISOTOPES AND ELEMENTS

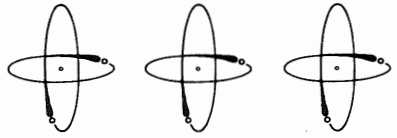
CRACKING THE ATOM



The nucleus, heart of the atom, can be broken apart by bombarding it with nuclear particles. The usual "bullets" are protons, deuterons, and alpha particles, but the Hilac uses heavier particles. The target may give off protons, neutrons, deuterons, or alpha particles. If larger fragments appear, the reaction is known as *spallation*. Sometimes the target is broken into two approximately equal parts and releases large amounts of energy. This is known as *fission*. By all these transformations information is gathered about the forces that hold the nucleus together. New facts are learned about nuclear processes; new isotopes and new elements may be created and studied.

WHAT ARE ISOTOPES?

All elements have atoms, the nuclei of which have more than one atomic weight, though they are chemically identical. These slight variations are caused by different numbers of neutrons in the nuclei. Thus oxygen of atomic weight 16 has 8 protons and 8 neutrons; oxygen 17 has 8 protons and 9 neutrons, oxygen 18, 8 protons and 10 neutrons. These atoms are known as *isotopes* of oxygen.



OXYGEN 16	OXYGEN 17	OXYGEN 18
PROTONS 8	PROTONS 8	PROTONS 8
NEUTRONS 8	NEUTRONS 9	NEUTRONS 10
ELECTRONS 8	ELECTRONS 8	ELECTRONS 8

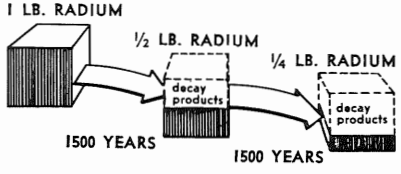
DISCOVERING NEW ISOTOPES AND ELEMENTS

When an atom's nucleus captures or ejects a particle, it becomes a different kind of atom (transmutation). This may occur (a) *naturally*, as in radium from which alpha particles are ejected until a radium atom eventually becomes an atom of lead; or (b) *artificially*, when a substance is bombarded with particles, by which means radioactive isotopes and new elements may be formed.

New isotopes are discovered with high-energy particle accelerators, and are produced in quantity in nuclear reactors, or piles. Carbon-14, important research "tracer" isotope, is formed by the bombardment of nitrogen by neutrons.

Uranium, element 92, at one time the "last" of the elements, when bombarded by neutrons turns into short-lived neptunium and then into long-lived plutonium, which can be used in destructive bombs and constructive reactors. In this laboratory the number of elements was extended to 101 and hundreds of new isotopes of well-known "old" elements have been made.

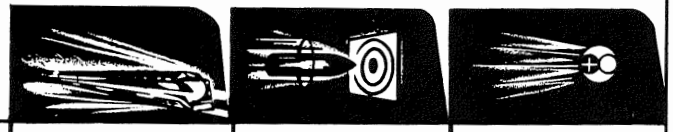
RADIOACTIVITY



Many isotopes are unstable. They are prone to change into other nuclei by ejecting particles. Such isotopes are *radioactive*. The radiations given off may be in the form of alpha particles (alpha rays), electrons (beta rays), or electromagnetic radiation (gamma rays). Radium is naturally radioactive, emitting alpha particles at such a rate that half a given quantity is transformed in 1500 years (its half life).

8 ENERGIES AND MASS INCREASE OF ACCELERATED PARTICLES

A deuteron accelerated to 200 Mev by the 184-inch cyclotron attains a velocity of 80,000 miles per second, or over 42% the speed of light! Although the mass of this atomic projectile is exceedingly small, this enormous velocity represents tremendous kinetic energy for one atom. It has 200 million times the energy of a lead atom in a high-power rifle bullet, and 333 billion times the energy of an iron atom in a speeding locomotive.



MASS	300 tons or 271,000,000 grams	.0175 lb. or 79.1 grams	3.70×10^{-24} grams (.000000000000 0000000000037) grams
VELOCITY	100 m.p.h. or 44.7 meters/sec.	3000 ft./sec. or 914 meters/sec.	421,000,000 ft./sec. or 128,000,000 meters/sec. (42% speed of light)
NO. OF ATOMS	2.9×10^{30} (2,900,000,000,000, 000,000,000,000, 000,000)	2.3×10^{23} (230,000,000,000, 000,000,000,000)	1
TOTAL KINETIC ENERGY (electron volts)	1.69×10^{27} (1,690,000,000,000, 000,000,000,000,000)	2.07×10^{23} (207,000,000,000, 000,000,000,000)	200×10^{6} (200,000,000)
ENERGY (electron volts) **PER ATOM**	.006	1	200,000,000

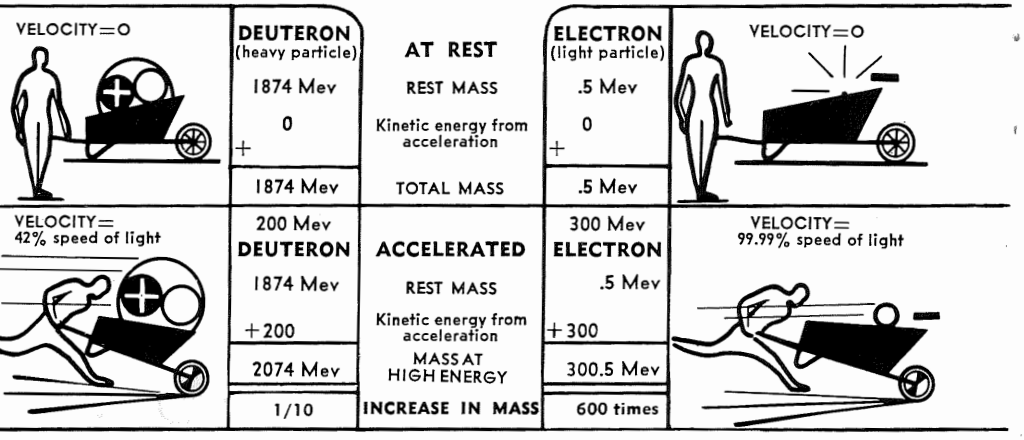
According to Einstein's now famous equation relating energy and mass:

$$E = mc^2$$

where E = energy
m = mass
c = velocity of light

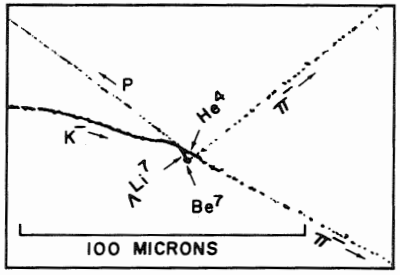
one can express the *mass* of an atomic particle in terms of *energy units* or vice versa, express its *energy* in terms of *mass units*.

On this basis the rest mass of a deuteron is 1874 Mev while that of an electron is 0.5 Mev. The following illustration demonstrates the relativistic or Einstein mass increase of atomic particles accelerated to high energies. A deuteron accelerated to 200 Mev increases in weight by about 10% while an electron accelerated to 300 Mev increases its mass 600 times.



HYPERONS AND ANTIPARTICLES

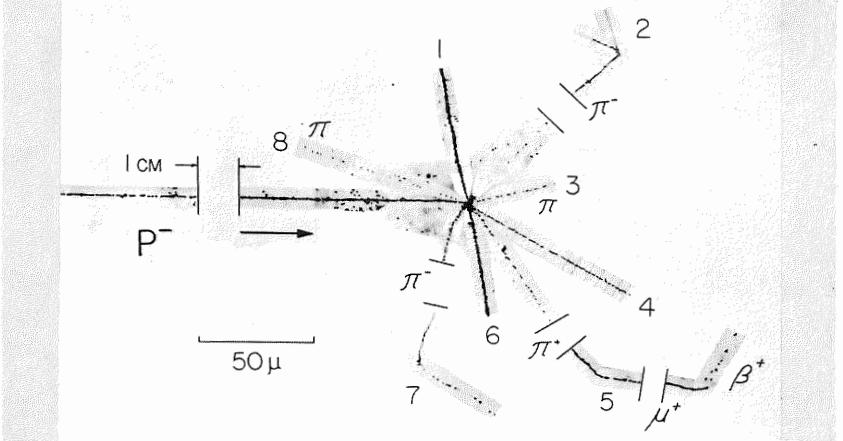
Bombardment of matter with the 6.2-Bev proton beam in the Bevatron produced not only the expected and wanted mesons but also a crop of new "strange particles," some with masses greater than protons. They are given Greek-letter names such as lambda (Λ), sigma (Σ), and xi (Ξ), or cascade particles. They are very short-lived and decay into other particles.



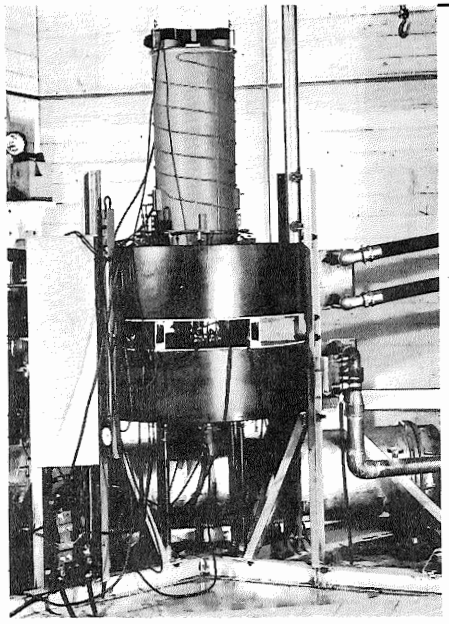
CAPTURE OF A NEGATIVE K MESON BY A CARBON NUCLEUS LEADS TO EMISSION OF A $_\Lambda Li^7$ HYPERFRAGMENT. A HYPERFRAGMENT IS AN UNSTABLE NUCLEUS CONTAINING A Λ HYPERON.

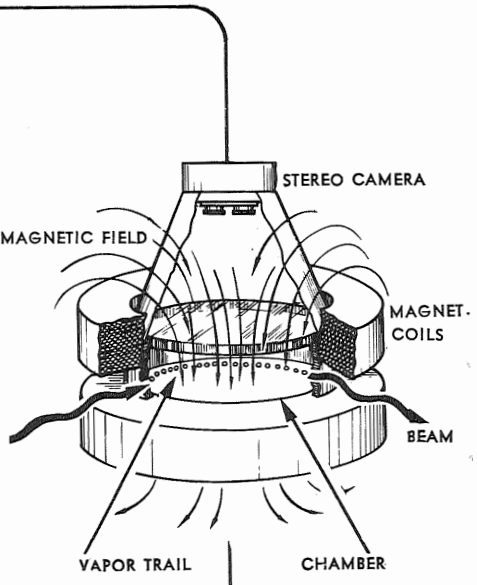
In 1928 Dirac predicted that the electron would be found to have a positively charged counterpart ("antiparticle"). It was found in 1932 by Anderson and named the positron. An electron-positron pair can be created directly out of energy. The same theory says that there should also exist a negatively charged "antiproton." Given a sufficiently powerful accelerator (only the Bevatron and cosmic rays are adequate), one should be able to produce proton-antiproton pairs. This was accomplished in 1955 by a group at the Radiation Laboratory. Proton-antiproton pairs can "annihilate" and transform back into energy and other particles, as shown in the photograph below.

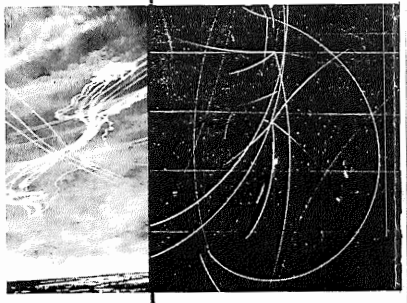
This star was the first observed for which annihilation could be established. In this star a visible energy release of 1,300,000,000 electron volts (1.3 Bev) was observed. Such energy release is greater than can be obtained from the destruction of only one particle of protonic mass. A proton and an antiproton must have been completely destroyed.



THE CLOUD CHAMBER







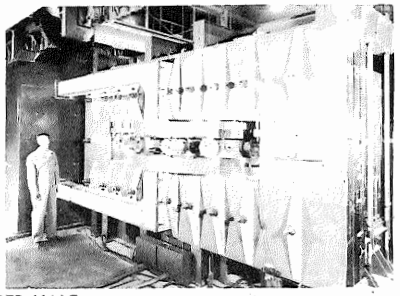
The cloud chamber provides another means of taking photographs of tracks made by particles. In this case, the tracks are made in a gas rather than in a photographic emulsion. A quick reduction of pressure in the chamber produces a supersaturated vapor. High-energy charged particles passing through the chamber ionize atoms of the vapor along their path. Moisture condenses on the trails of ions and simultaneously a photograph is taken of the event.

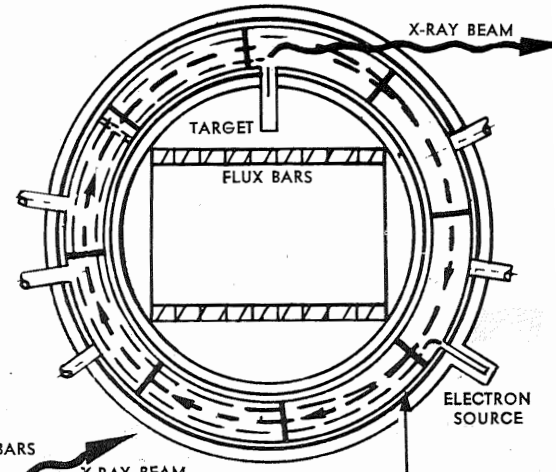
Photographs of these fog drop trails give the physicist information on what the particle was, how much energy it had, and what happened when it hit another atom.

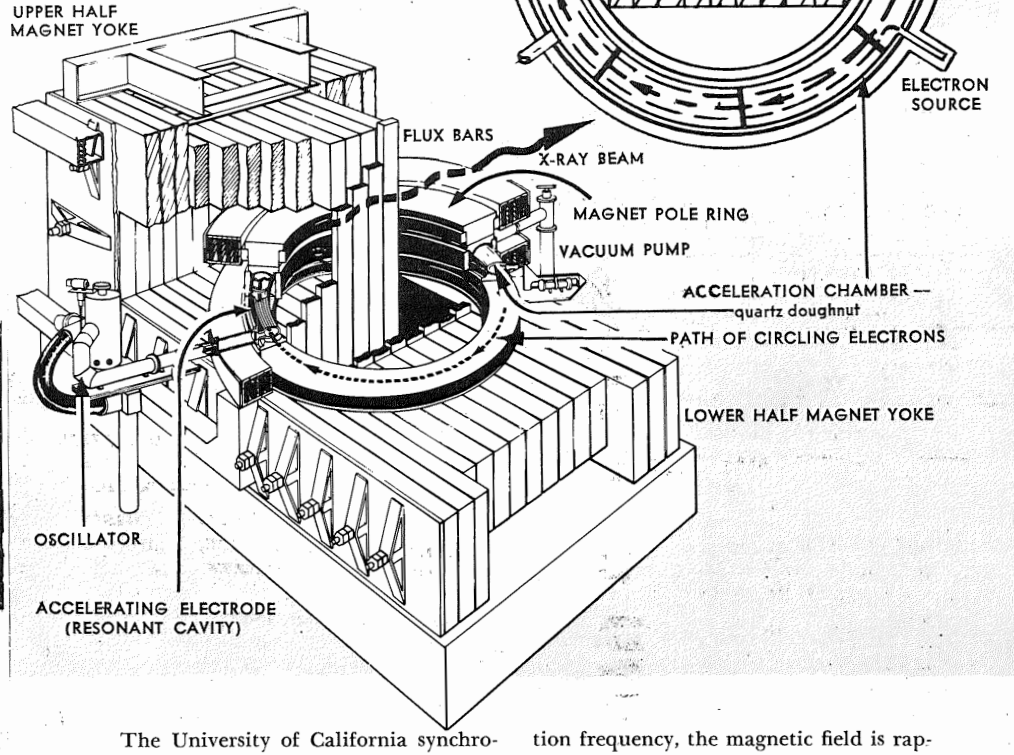
The effect is not unlike the vapor trail of a high-flying airplane. The high-speed particles, like the planes, are invisible, but both leave a visible vapor trail.

The value of cloud chamber photographs is greatly enhanced when the chamber is placed in a magnetic field, which curves particles going through the chamber. The degree of curvature is a key to the energy of the particle. Note the increasing curvature of the proton track as the proton loses energy and comes to rest.

THE SYNCHROTRON Accelerates: electrons e^-





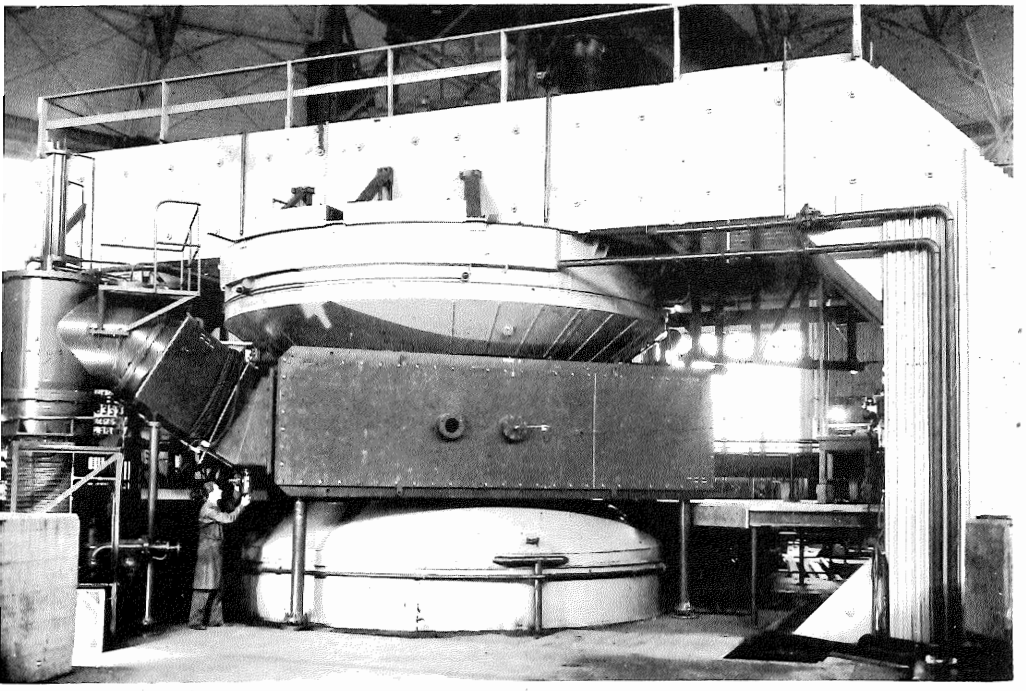


The University of California synchrotron whirls electrons to high energies by a series of electric kicks, similar to cyclotron action. Electrons are first accelerated to 2 Mev by betatron (or transformer) action, then are boosted to more than 340 Mev by applying an alternating current to the accelerating electrode. In contrast to frequency modulation in the synchrocyclotron, the acceleration frequency in the synchrotron is held constant. To compensate for the Einstein mass increase at higher energy and pull the electrons into step with the acceleration frequency, the magnetic field is rapidly increased. This is accomplished by discharging electric current from condensers through the magnetic winding.

An electron accelerated in this machine to 340 Mev will make 400,000 revolutions at almost the velocity of light, traveling 1600 miles in 1/120 second.

Upon reaching maximum energy, electrons are made to spiral inward to strike a metal target, producing high-energy X-rays for nuclear bombardments and research.

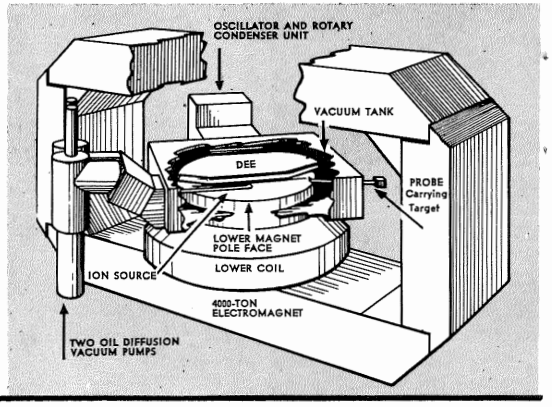
THE 184-INCH SYNCHROCYCLOTRON



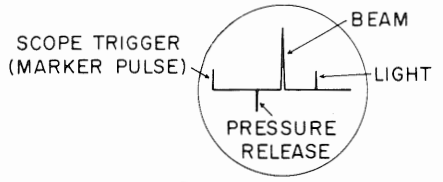
The theory of relativity states that as a particle gains energy it also gains mass (weight). This gain in mass causes it to fall behind the equally timed impulses of a simple or conventional cyclotron.

In the 184-inch cyclotron the frequency of oscillation is made to slow down as the particles speed up, so that many more impulses are applied "inphase" and particles are given greater final velocity and energy. Accordingly it is called a frequency-modulated (FM) cyclotron or synchrocyclotron.

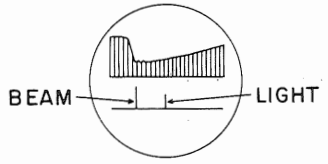
The 184-inch cyclotron gets its name from the fact that its magnetic pole faces have that diameter. For years its 4000-ton magnet had a 15,000-gauss field strength, which allowed protons to be accelerated to 350 million electron volts (Mev). Recent changes (1957) have raised these values to 22,000 gauss and 735 Mev.



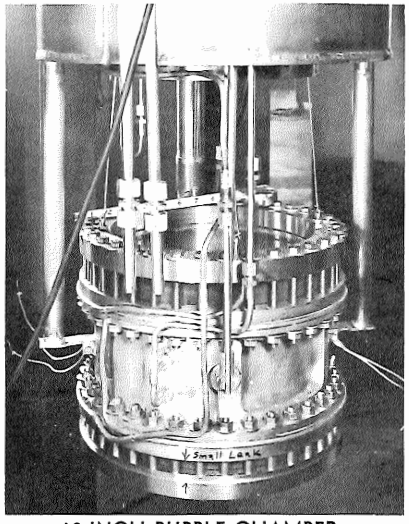
THE BUBBLE CHAMBER



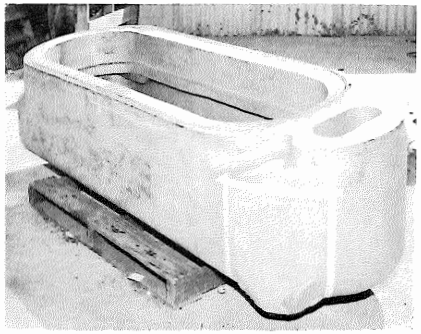
TYPICAL DELAY SCOPE PRESENTATION



TYPICAL PRESSURE SCOPE PRESENTATION



10-INCH BUBBLE CHAMBER



CASTING 72-INCH BUBBLE CHAMBER

The most recent device to make the paths of charged particles visible is the bubble chamber. The method of operation and results are similar to those associated with the cloud chamber. At the proper temperature and pressure a liquid can be heated above the temperature at which it should boil (turn into gas), but a bubble will not form unless it has some "seed" or nucleus to start from. Passage of a charged particle (ion) furnishes nucleation points, and a trail of gas bubbles results. A picture taken after a proper interval clearly shows charged-particle paths and events. (See front cover.)

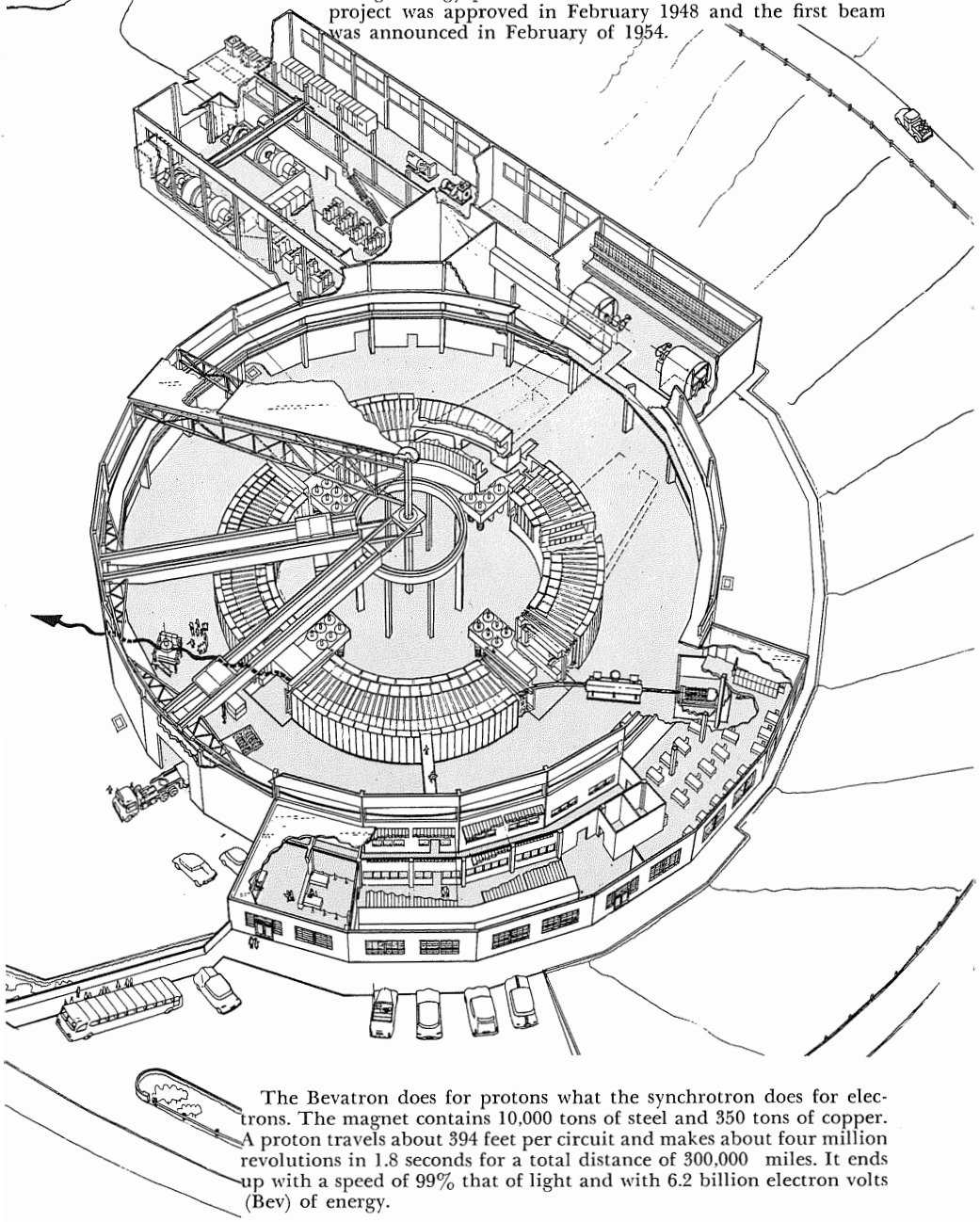
The original bubble chamber (invented by Dr. Donald Glaser) used diethyl ether for the liquid. Both propane and hydrogen have been used successfully at the Radiation Laboratory. The advantage of hydrogen is that it has only one kind of atom, and "hits" that result in "stars" can be more easily and surely interpreted. A difficulty is that very low temperatures are necessary to maintain hydrogen in a liquid state.

A 4-inch-diameter model operated very successfully. It used a pressure range of 5 to 6 atmospheres and a temperature range of 26° to 28° Kelvin. (Pure hydrogen boils at 20° K at atmospheric pressure.) The ionizing particles (from an accelerator) are admitted at a time of minimum pressure. The stroboscopic light, which takes the picture, is flashed 2 to 5 milliseconds later. (The series of events is illustrated in the scope diagrams above left.) Because the density in bubble chambers is higher than in cloud chambers, many more interesting nuclear events are observed in comparable operating intervals. (The sensitive medium is about 30 times as dense.) The 4-inch bubble chamber was followed by 10-inch and 15-inch chambers. As of December 1957, the 10-inch chamber had produced more than 600,000 photographs similar to that shown on the cover.

In 1957 designs were completed and construction began on a hydrogen bubble chamber 72 inches long by 23 inches wide by 15 inches deep. This large chamber should be operating in the summer of 1958.

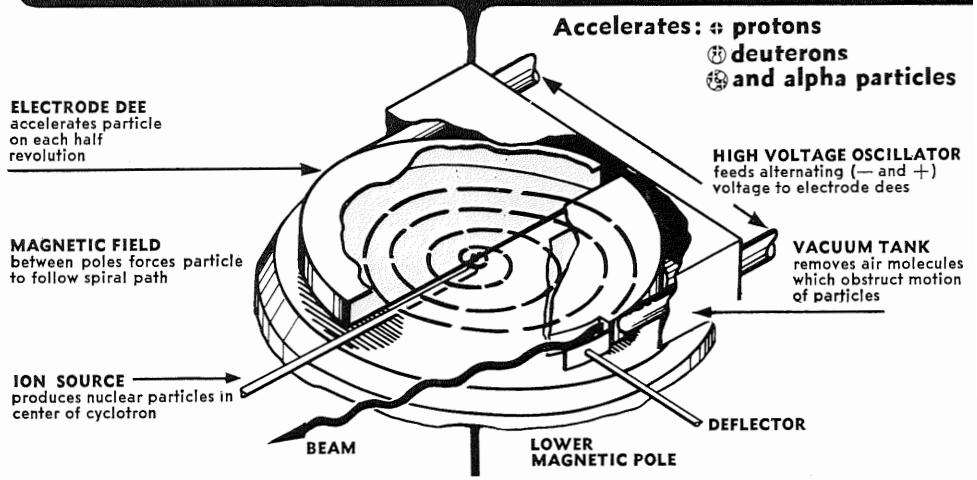
THE BEVATRON

Cosmic ray research and theoretical studies indicated that higher-energy machines would produce not only more but also different kinds of particles. This was verified when the big 184-inch synchrocyclotron first produced artificial mesons (as mentioned on page 13). To explore more fully this field of high-energy particles the Bevatron was constructed. The project was approved in February 1948 and the first beam was announced in February of 1954.



The Bevatron does for protons what the synchrotron does for electrons. The magnet contains 10,000 tons of steel and 350 tons of copper. A proton travels about 394 feet per circuit and makes about four million revolutions in 1.8 seconds for a total distance of 300,000 miles. It ends up with a speed of 99% that of light and with 6.2 billion electron volts (Bev) of energy.

THE CYCLOTRON: A Particle Accelerator

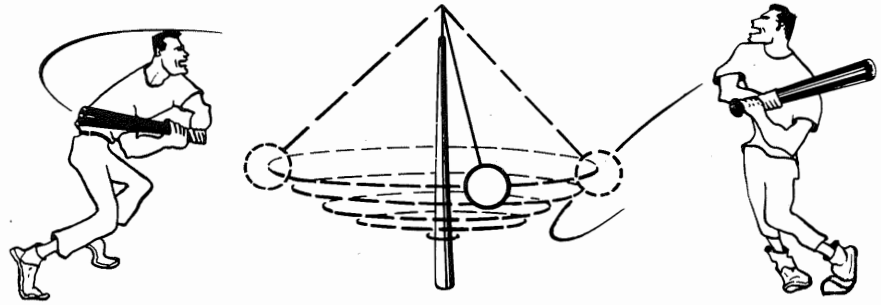


The essential parts of a conventional cyclotron are an electromagnet, a vacuum chamber between its poles, and two accelerating electrodes connected to a source of alternating voltage.

The operation begins when an ion source produces nuclear particles at the center of the accelerating chamber. Electrons emitted from a heated wire in the ion source knock the electrons from the atoms of entering gas, permitting the positively (+) charged nuclei to float up into the space between the two accelerating electrodes (*"dees"*). Depending upon whether hydrogen, heavy hydrogen or helium gas is used, the particles obtained for acceleration are protons, deuterons, or alpha particles.

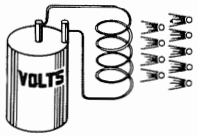
Between the dees, the particles are under the influence of two powerful forces: the magnetic field and the rapidly alternating electrical charge fed to the dees by the oscillator. The (+) charged particles are attracted to the negatively (—) charged dee, the attraction speeding them up. The magnetic field pulls the particles in a semi-circular path back to the space between the dees. Meanwhile, the charge on the dees has reversed, and the particles are repelled by the (+) charged dee and attracted to the opposite dee, now (—) charged. This process is repeated, the particles gaining speed and energy and traveling in ever widening circles until they near the outer edge of the dees. Here they are drawn out of the chamber by the deflector, and emerge as a beam of high-energy atomic projectiles.

In the 60-inch Crocker cyclotron a deuteron makes 100 revolutions in 8.3 millionths of a second attaining a speed of 29,500 miles per second and an energy of 24 Mev.



A particle being accelerated in a cyclotron is analogous to a ball fastened by a string to the top of a pole. Every half turn the ball is batted, thus increasing its speed and its energy. As its speed increases, it follows a spiral path, moving outward from the pole. If the batters were to strike the ball as frequently as a particle being accelerated in the 184-inch cyclotron, they would have to strike it 20 million times per second.

PRODUCING ATOMIC PARTICLES



Electrons are liberated by heat or electrical forces from the atoms of various materials: for example, from a tungsten wire brought to a high enough temperature by an electrical current, as in a radio tube. These electrons may be accelerated to bombard atoms.

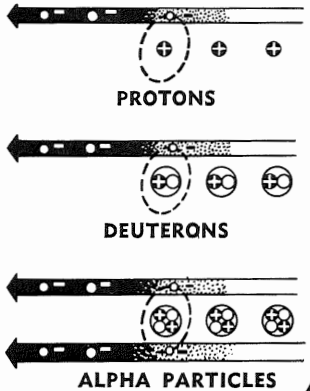
Protons are obtained when the electron is stripped from an atom of hydrogen, the remaining stripped nucleus being a proton.

Deuterons are similarly obtained from deuterium, the heavy hydrogen atom, the nucleus containing a neutron and a proton.

Alpha Particles, made up of two protons and two neutrons, are the stripped nuclei of helium.

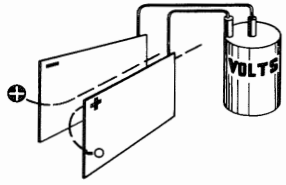
An arrangement for obtaining such particles is called an *ion source*.

Neutrons of high energy are produced by bombarding atoms with the above particles.



DIRECTING THE MOTION OF CHARGED PARTICLES

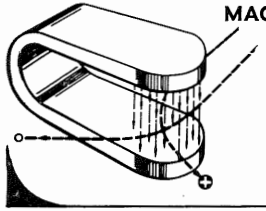
ELECTRICALLY



Charged (+ or —) particles are repelled by like electrical charge, and attracted by opposite electrical charge.

The degree of attraction or repulsion of the charged particles depends on the strength of the electrical field.

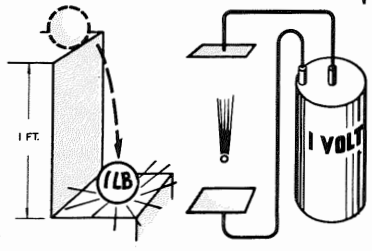
MAGNETICALLY



A charged particle in motion is influenced by a magnetic field. The field will bend negatively charged particles in one direction, positively charged particles in the opposite.

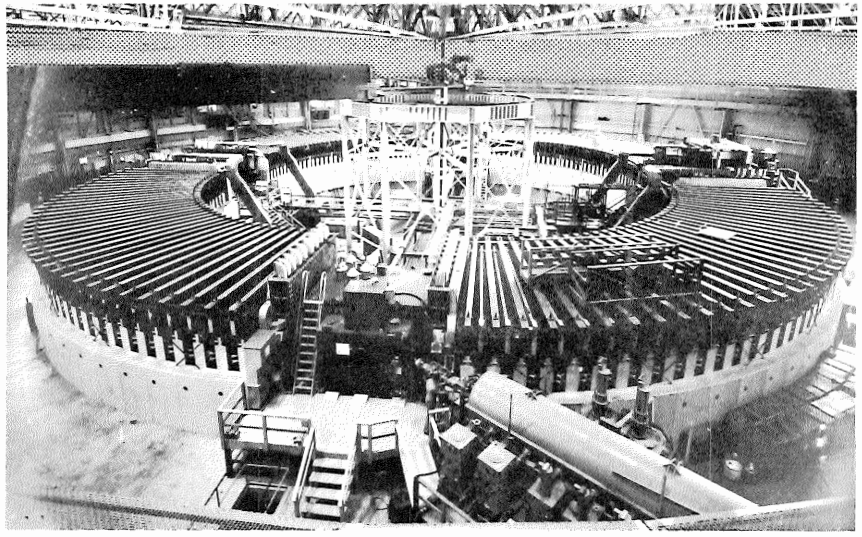
ACCELERATING ATOMIC PARTICLES

Charged particles are accelerated as they pass through an attracting electrical field, acquiring energy proportional to the difference of potential creating the field. The common unit for measurement of such energy is Mev or million electron volts. An electron volt is a unit of energy analogous to the foot pound, and corresponds to the energy acquired by one electron charge passing through a potential difference of one volt.

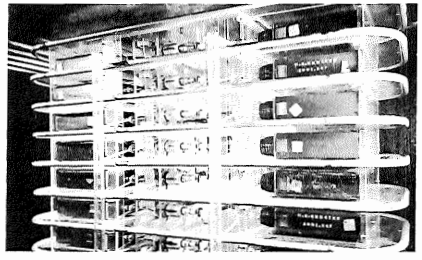


The protons are preaccelerated to 500 kev in a Cockcroft-Walton voltage doubler and then to 10 Mev in an 18-foot linear accelerator before being injected into the Bevatron itself. The magnetic field has a natural rate of rise from 300 gauss to 15,000 gauss and the frequency of the rf system is tied in with this to keep the protons both focused and accelerated. When the beam is allowed to hit a target, large streams of various decomposition products are formed, including mesons, hyperons, and antiparticles. These are now being intensively studied. Some pictures of their reactions are shown on page 13.

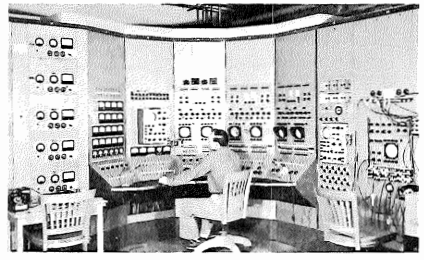
BEVATRON WITH LINAC INJECTOR IN FOREGROUND



COCKCROFT-WALTON POWER SUPPLY



BEVATRON CONTROL ROOM



An important new detection device has been developed which helps in this study. It is known as a Cherenkov counter. It depends on the fact that when a charged particle travels through matter faster than light can travel through that same matter it sets up a "shock wave" of energy (light) very much like the bow wave of a boat moving through still water. This light, though rather feeble, is definite, and its effect can be caught and magnified by photomultiplier tubes. The reaction time is less than for other detectors. Events that happen only a billionth of a second apart can be resolved.

When elements are bombarded by high-speed particles the nucleus of the target first (but frequently temporarily) absorbs the projectile to make an unstable new nucleus which later decays in various ways. It was thought that if heavier projectiles were used two classes of elements might be formed:

(1) new heavy elements (beyond 101),
(2) new neutron-deficient isotopes of middle-weight elements.

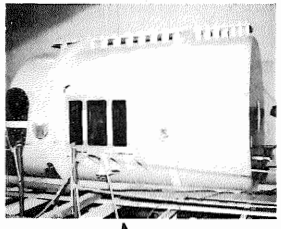
To explore these possibilities (and others) a heavy-ion accelerator was built. It accelerates ions from elements as heavy as neon.

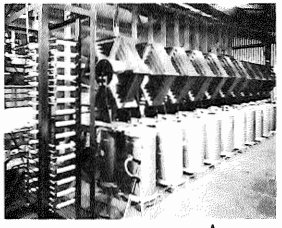
A diagram of the Hilac and photographs of the actual parts are shown below.

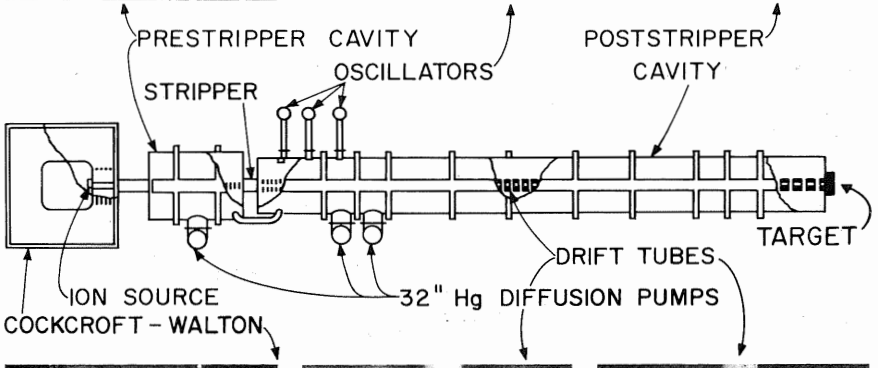
The Cockcroft-Walton gives 0.071 Mev energy per nucleon to the projectiles. The prestripper linac increases this through 37 drift tubes in 15 feet to 1 Mev per nucleon.

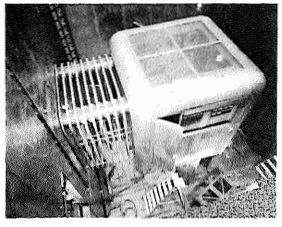
The "stripper" is a transverse jet of mercury which knocks more electrons off the ions so that they have higher positive charge and respond better to accelerating forces in the poststripper. This makes possible a shorter second cavity (90 feet) and much less expenditure of energy. Particles finally emerge with 10 Mev energy per nucleon at a speed of approximately 28,000 miles per second. Both cavities oscillate at 70 Mc. Operating pressures are 2×10^{-6} millimeter of mercury. Focusing in the first cavity, because of the small dimensions, must be by electrostatic grids which scatter and lose 5/6 of the beam, but the 68 20-inch-diameter drift tubes in the second cavity have alternate-gradient or "strong" magnetic focusing, and focus all the beam without loss.

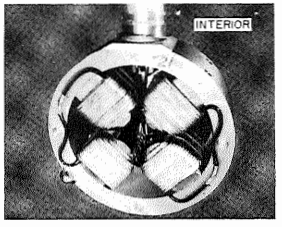
The project was approved February 1954 and the first accelerated beam was obtained April 20, 1957.

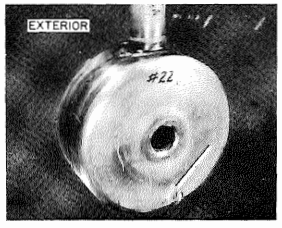












MEET THE ATOM

ALL MATTER IS COMPOSED OF ATOMS, UNITS SO SMALL THAT 20 MILLION WOULD JUST SPAN A PIN'S HEAD

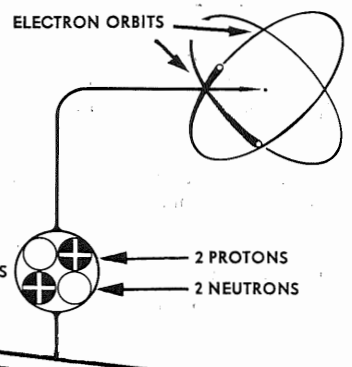
Though invisible, an atom is something like a tiny solar system, with a nucleus composed of neutrons and protons, and electrons whirling around this central body.

Neutrons and protons have approximately the same mass (weight), but the neutron is electrically neutral while the protron is electrically positive (+).

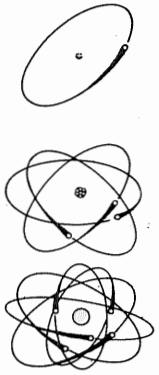
Electrons are electrically negative (—), and are so light that it would take 1840 of them to make one proton or neutron.

For every (+) proton in the nucleus there is always one planetary (—) electron.

THE HELIUM ATOM ENLARGED 100 MILLION TIMES WOULD LOOK LIKE THIS:



THERE ARE 92 NATURALLY OCCURRING KINDS OF ATOMS



ATOMIC WEIGHT

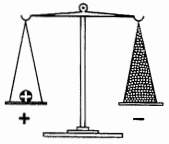
— HYDROGEN 1 — 1 PROTON in the nucleus
1 ELECTRON whirling around it

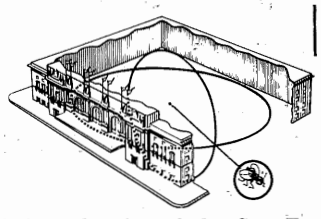
— OXYGEN 16 < 8 PROTONS, 8 NEUTRONS in the nucleus
8 ELECTRONS whirling around it

— URANIUM 238 < 92 PROTONS, 146 NEUTRONS in the nucleus
92 ELECTRONS whirling around it

MEET THE NUCLEUS

IT IS 10,000 TIMES SMALLER THAN THE ATOM





An atomic nucleus is made up of one or more protons and neutrons. Because of the great density of these nuclear particles, which are 1840 times as heavy as electrons, 99.95% of an atom's weight is in the nucleus. A nucleus as big as the one diagrammed above would weigh as much as 8000 battleships.

Despite its small size, an atom is mostly empty space, the nucleus occupying only a fraction of the total volume. If an atom were expanded to the size of the San Francisco Auditorium, the nucleus would be no larger than a housefly.

Fundamental changes in atoms can be made only by altering their nuclei, that is, by adding or removing a proton or neutron.

THE LABORATORY

The Radiation Laboratory was established in 1936 as a part of the Department of Physics of the University of California. From the beginning much effort has been concentrated on the development of particle accelerators because of the great importance of these machines for probing the atomic nucleus.

The research program of the Laboratory has always had as its principal theme the investigation of the fundamental aspects of physical science. As the program and facilities expanded, interests spread beyond the field of physics into chemistry, biology, and medicine. The present research effort extends quite broadly over the entire range of basic research on the fundamental physical and chemical properties of matter and on the application of radioactive substances to problems in biology, medicine, and related fields. The training of graduate students and junior scientists is tied into the research program and is regarded as an important phase of the Laboratory's work.

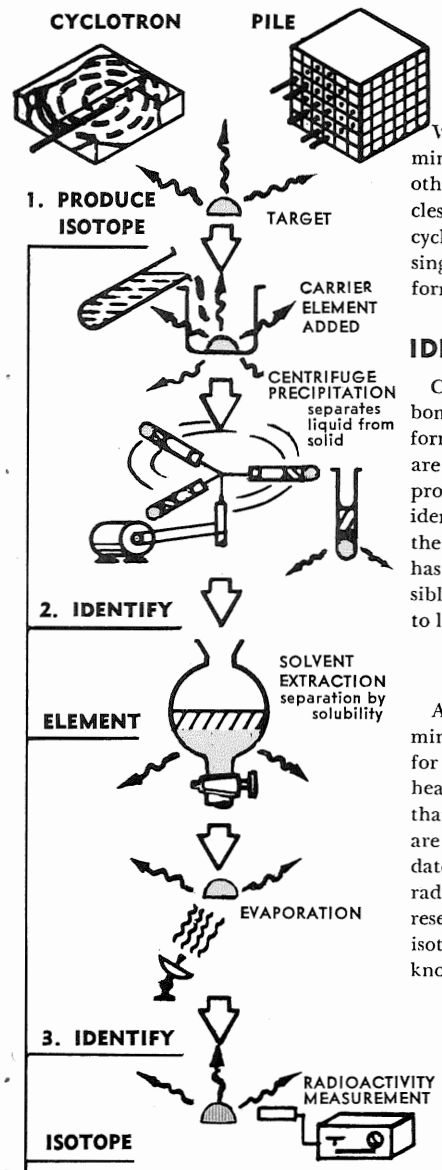
During the wartime period the Laboratory was engaged under the Manhattan Engineer District in the development of an electromagnetic isotope-separation process. This work led to the construction of a large plant at Oak Ridge for the electromagnetic separation of uranium isotopes. The Government sponsorship of research has continued on a large scale under the Atomic Energy Commission, so that the Radiation Laboratory is now almost completely supported by the Commission through a contract with the University of California.

The interest and cooperation of scientific workers everywhere have been gratifying and encouraging to members of this Laboratory.

CLARK KERR
President, University of California

NUCLEAR CHEMISTRY

Nuclear chemistry deals with nuclear reactions, their products and applications. It includes radiochemistry—the application of radioisotopes and nuclear methods to chemical problems in general.



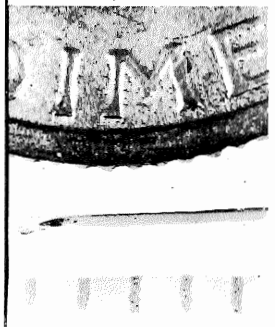
When high energy particles bombard a target material, a minute percentage of the target atoms may be transmuted into other elements, chiefly radioactive or unstable isotopes. Particles of such high energy as those produced by the 184-inch cyclotron may break off from one to a dozen particles from a single target nucleus, the isotopes of many elements being formed in a single bombardment.

IDENTIFICATION

Chemical processes are necessary to separate and identify bombardment products. Because cyclotron-made isotopes are formed in such small, unweighable amounts, stable elements are often added—elements suspected of being among the products. This facilitates chemical processing to isolate and identify the elements formed. Radioactivity measurement of the isolated element discloses which isotope of that element has been produced. Such positive identification makes it possible to understand what happened in the bombardment and to learn more about the fundamental properties of the nucleus.

RESEARCH

As new isotopes are identified, chemists set about to determine their chemical and nuclear properties. In some instances, for example, in the case of plutonium and other elements heavier than uranium, more is known about their properties than about many naturally occurring elements. New isotopes are continually being discovered, identified and studied. To date, over a thousand have been found, and one or more radioactive isotopes are now known for every element. Such research may uncover some immediate practical use for a new isotope, and is continually expanding the horizons of chemical knowledge.



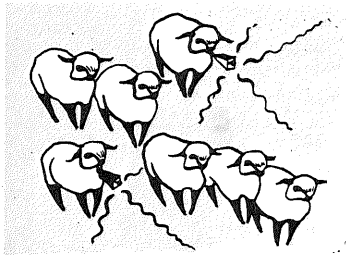
10 micrograms of pure neptunium oxide at bottom of capillary tube. The neptunium was produced by cyclotron neutrons. A 10-cent piece and a millimeter scale are shown for size comparison.

TOOLS AND TECHNIQUES

The nuclear chemist is usually forced to work with extremely minute quantities of material, often intensely radioactive. This has given rise to new chemical techniques, means of weighing and handling minute amounts, and shielded manipulators to protect personnel from radiation or toxic hazards. Of note is the new radiochemistry (tracer or "tagged atom") technique in which chemical properties are investigated in amounts so small as to be unweighable: reactions are studied by following radioactivity rather than conventional chemical analysis.

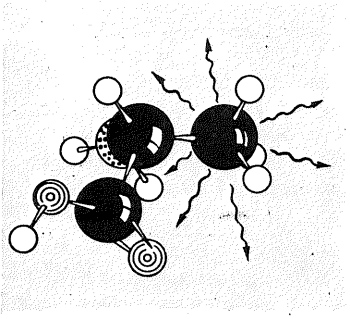
APPLICATIONS OF

BIOLOGICAL CHEMISTRY



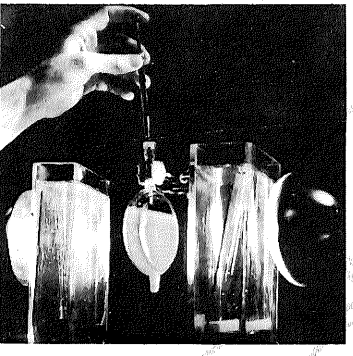
TRACER TECHNIQUE

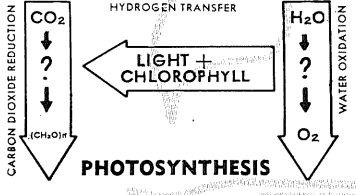
The use of radioactive isotopes as tracers, whether in biological, medical, industrial or other research, is fundamentally the same. Elements or compounds are "tagged" with radioactivity, which permits the researcher, equipped with a Geiger counter, to follow their path in the body, in a plant, or in a test tube. This is much like tying a bell around the neck of a few sheep in a pasture — the flock can then be located by the sound of the bells.



PREPARING C^{14}-TAGGED COMPOUNDS

Biological research deals principally with organic (carbon-containing) compounds. There are several thousand varieties of these compounds, including petroleum products, alcohols, sugars, starches, amino acids, hormones, fats, etc. A chemist can build the most useful radioactive isotope of carbon, C^{14}, into the complex molecules of these compounds, permitting scientists to trace these tagged molecules and the products into which they may be converted. Carbon 14 is thus a research tool of major importance in biological studies. The synthesis of C^{14}-tagged substances is a continuing program of the Radiation Laboratory.





PHOTOSYNTHESIS

Photosynthesis is the process whereby carbon dioxide and water plus energy from the sun become carbohydrates. This is usually catalyzed by chlorophyll, the green material in growing plants. In the process oxygen is released to the atmosphere. This, plus the nitrogen cycle, accounts for the growth of all living things.

The path of photosynthesis is not as simple as the end products would indicate. The isotope carbon-14, which is radioactive and thus "takes its own picture" on photographic film, has been indispensable in tracing the intermediate steps. This isotope used in two-dimensional chromatography has enabled workers at UCRL to untangle many of the steps in the devious route.

A complete understanding of photosynthesis should enable man to apply this fundamental process to worldwide problems. Thus the total world food supply could be increased, or more of the sun's energy could be converted into "frozen" chemical energy in the form of coal, oil, wood products, etc.

NUCLEAR RESEARCH

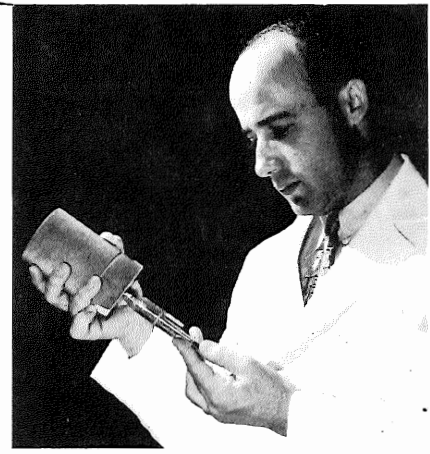
UCRL

UNIVERSITY OF CALIFORNIA
RADIATION LABORATORY, BERKELEY

COVER: Photograph of "strange-particle" production and decay in a 10-inch hydrogen bubble chamber.

MEDICAL RESEARCH

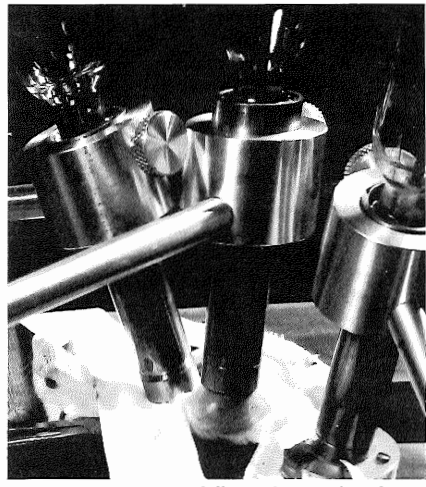
Radioisotopes have been used in the study of certain medical problems for several years, and today they are finding increasing usefulness in research on a variety of diseases. Among such isotopes are those of the elements iodine, phosphorus, carbon, sodium, iron, cobalt, hydrogen, yttrium, strontium and gold.



A brass shield and lucite syringe protect the doctor from excessive radiation as he prepares a suitable injection of radiophosphorus for a leukemia patient. →

RADIOISOTOPES AS TRACERS

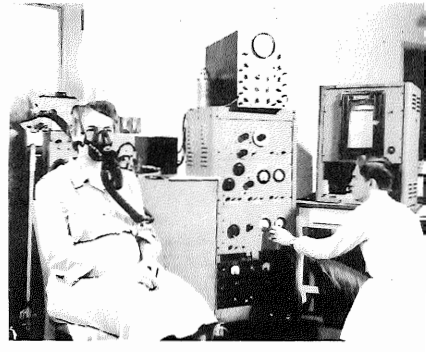
The most important application of atomic energy to medicine is the use of isotopes in minute amounts as tracers to gain a greater understanding of disease processes. With radioactive iron, for example, it is possible to discover new subtleties of anemia. Hidden facets of the synthesis of proteins, complex "living" chemicals made up of amino acids, become apparent when radioactive forms of amino acids are administered to animals. Fat molecules, "tagged" with radioactive carbon, help bring new understanding of diabetes. With the knowledge gained from such research, physicians are developing new techniques for the diagnosis and treatment of disease.



Geiger counters follow the path of radiophosphorus in a mouse by checking the activity over the liver, tumor (cancer), and leg bone.

RADIOISOTOPES FOR THERAPY

Since radioisotopes emit the same types of radiations as X-rays and radium, their general effect on tissue is the same. Hence the logical sequel to the tracer work is the development of radioactive compounds which will localize in radiosensitive diseased parts. Where this is possible, one may attack disease by selective radiation without causing serious damage to normal tissues. Promising results have been obtained in treating polycythemia and some kinds of leukemia, two blood diseases. Efforts are being made to apply this "selective localization" principle to cancer. While such work is adding to our medical knowledge and is aimed ultimately at methods of controlling disease, much further research is necessary before these objectives can be realized.



A mass spectrograph, which identifies isotopes by their atomic weight, is used in the study of heart disease and polycythemia.

Because the scope of atomic research is large, this booklet is necessarily limited to a summary of the type of research carried on at the Radiation Laboratory of the University of California. No attempt has been made to give credit for similar work done at other institutions.

Broad fields of atomic research are being explored elsewhere both with and without the assistance of the Atomic Energy Commission — in AEC laboratories, in universities and in industrial laboratories. The wide range of investigations includes such important problems as the practical conversion of atomic energy to power and the more efficient use of fissionable materials in nuclear reactors.

SUGGESTED READING ON NUCLEAR RESEARCH AND ATOMIC ENERGY

POPULAR

MR. TOMPKINS EXPLORES THE ATOM
George Gamow
The McMillan Co., 1944

EXPLAINING THE ATOM
Selig Hecht
The Viking Press, Inc., 1947

WHY SMASH ATOMS?
A. K. Solomon
Harvard University Press, 1946

ATOMIC ENERGY
Karl K. Darrow
John Wiley, 1948

SMYTH REPORT
Princeton University Press, 1946

TEXTS—MINIMUM MATHEMATICS

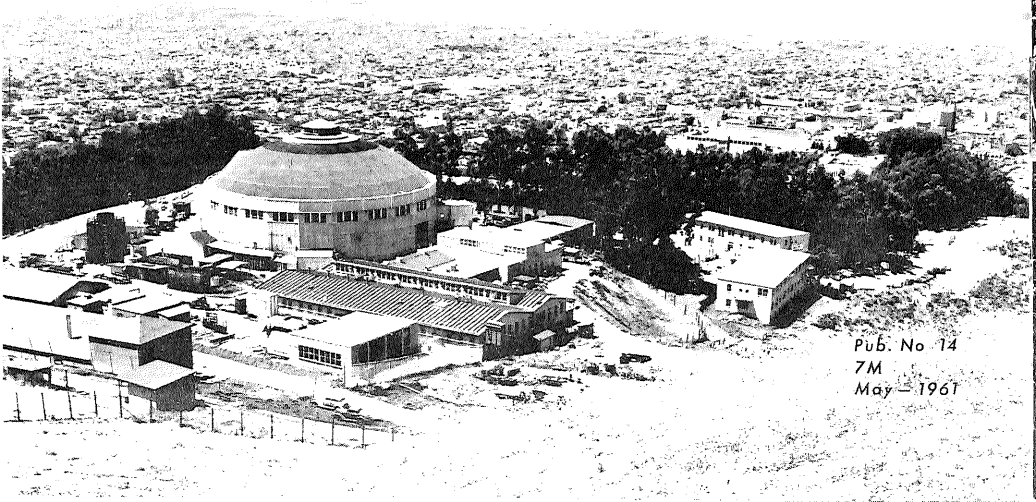
SOURCE BOOK OF ATOMIC ENERGY
Samuel Glasstone
D. Van Nostrand, 1950
(new edition 1958)

THE PARTICLES OF MODERN PHYSICS
J. D. Stranathan
Blakiston Press, 1942

APPLIED NUCLEAR PHYSICS
Pollard & Davidson
John Wiley, 2nd ed., 1951

FUNDAMENTALS OF ATOMIC PHYSICS
Saul Dushman
McGraw-Hill, 1951

MODERN PHYSICS FOR THE ENGINEER
Louis Nicot Ridenour
McGraw-Hill, 1954



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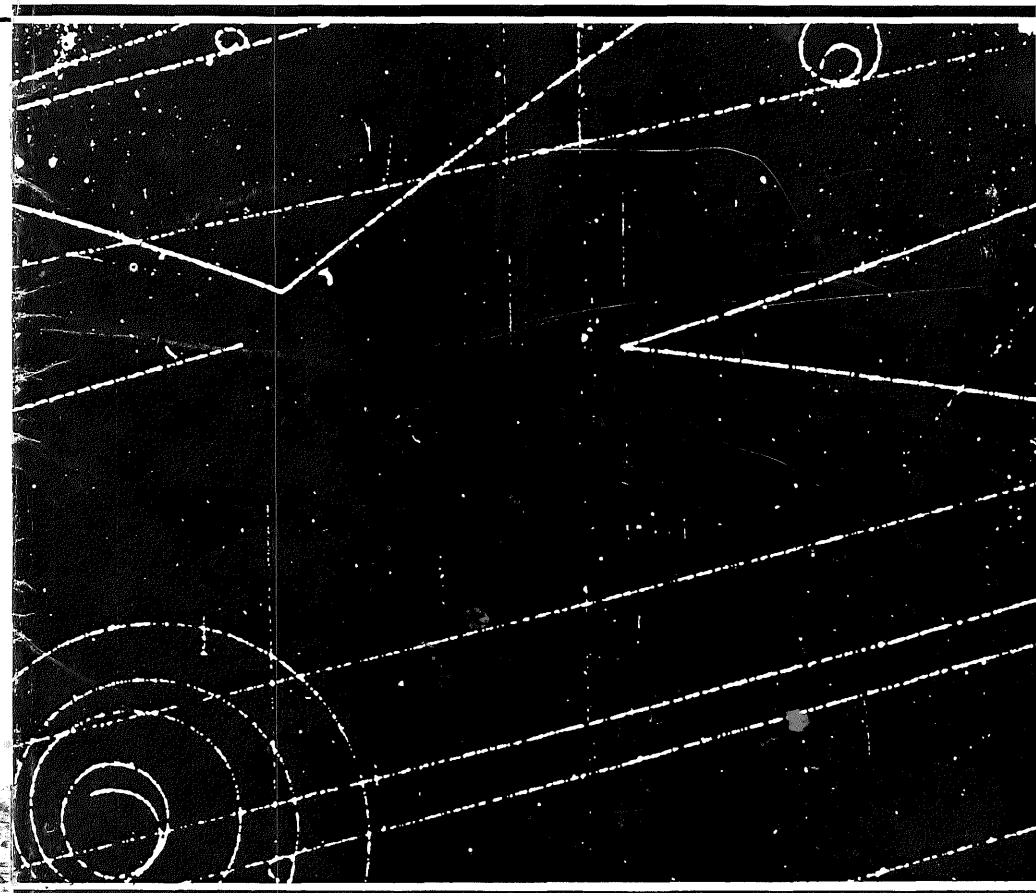

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